AD-779 407

A LITERATURE REVIEW OF COCKPIT LIGHTING

HUMAN ENGINEERING LABORATORY

APRIL 1974

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AD 779 407

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Memorandum 10-74	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A LITERATURE REVIEW OF COCKPIT LIGHTING		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Alan M. Poston		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Human Engineering Laboratory Bldg. 520 Aberdeen Proving Ground, MD 21005		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS AMCMS Code 612106.11.A5500
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE April 1974
		13. NUMBER OF PAGES 27
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Cockpit lighting
dark adaptation
visual acuity
Human Factors Engineering

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report contains a compilation of data from a review of the available literature on the subject of cockpit lighting. The purpose of this review is to pinpoint areas where sufficient results have been obtained to prevent the repetition of similar studies. It is also the intent of this report to point out areas where future research is needed before improvements in current lighting systems can be made. The major areas of discussion are red versus white, major cockpit lighting problems, auxiliary lighting, glare reduction, luminance levels and legibility, and future considerations. Within each section, conclusions and recommendations have been made based on the information presented.

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AMCMS Code 612106.11.A5500

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A LITERATURE REVIEW OF COCKPIT LIGHTING

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April 1974

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A LITERATURE REVIEW OF COCKPIT LIGHTING

INTRODUCTION

Cockpit lighting systems have always presented problems to the pilot. The problem has been compounded with the advent of more sophisticated crew station displays and more demanding tactical situations. Even the controversy of red versus white cockpit lighting is still unresolved. Therefore, as a prelude to cockpit lighting studies to be conducted by the U. S. Army Human Engineering Laboratory, this literature review was conducted. The purpose of the literature review was to gather whatever material is available in the area of cockpit lighting for the purpose of determining in what areas definite answers have been obtained and where specific problems lie. By doing this, some guidelines can be established for future research such that studies will be aimed at solving specific problems and not reproducing data that is generally known and accepted.

Also, an attempt will be made to define the mission requirements of the helicopters which will benefit from this literature review. Some conclusions are made by evaluating the data in terms of the mission requirements.

DISCUSSION

Red Versus White

For years the controversy over red versus white cockpit lighting has continued. Numerous studies have been conducted as well as a vast number of manhours evaluating the data, and yet the solution doesn't seem any closer now than when the debates first began. The prime rationale for a red lighting system is that it provides better dark adaptation and allows for maximum external vision. Almost all studies concerning this point have proven the statement to be true. It has been shown that night vision may be seriously impaired even by low levels of white lighting (32). Red lighting results in slightly superior ability of the pilot to see dimly illuminated objects outside the aircraft at night (27). In a comparison of the dark adaptation index (retinal sensitivity) loss of adaptation was greater with white for panels lit to a level giving equal legibility (41). It was also shown that a subject exposed to red light regains his response to fainter light sources more quickly than does the subject exposed to white light and reaches the level of complete adaptation sooner (29). When mission requirements demand a maximum level of dark adaptation, consideration should be given to a red lighting system. However, for less stringent dark adaptation requirements, the use of any other color display illumination is acceptable (54). It was pointed out that at minimum levels of instrument illumination, the advantage of dark adaptation from red is relatively small and can be easily be lost (27, 31).

The advocates of a white lighting system feel that maximum dark adaptation is not a prime requirement, but more important is the ability of the pilot to read all his internal information. It has been proven that color markings and map and chart features, which are often color coded, are more distinguishable under a white lighting system (5, 16, 17, 22, 26, 28, 64). Many pilots feel that white lighting gives a more natural appearance of things in the cockpit (42). Another possible reason favoring white light is that, depending on a particular pilot's accommodative condition, he may have slightly greater difficulty maintaining visual accommodation with red light because the longer wave lengths require more elastic accommodation of the lens in order to achieve focus on the retina (28).

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As the problem is concerned with dark adaptation, perhaps a few words about the rods and cones would be beneficial. We know that the rods are more sensitive in a detection task than the cones and that maximum sensitivity of the rods is achieved by dark-adapting them. However, we also know that the cones are required for resolution of fine detail. Perception of color is also a function of the cones. After the cones are fully dark-adapted, they can be exposed to low brightness for a short time and then regain full dark adaptation almost immediately, while the dark adaptation of the rods is harmed to a much greater extent (64). It should be noted that even after recovery of dark adaptation in the cones the sensitivity is less than in the completely (rod) dark adapted individual.

The luminance levels necessary for adequately reading displays are, at best, in the mesopic (both rod and cone) range, and most are in the photopic (cone) range. This means that the comparison of the effects of pre-exposure to different colors of light must be made from displays equated on the basis of photopic luminance. Most targets to be located or identified will most likely be at scotopic levels where the perception of light is a function of the rods. If the relative sensitivities of the rods and cones were the same, the color of the cockpit lighting would not matter. However, there are differences. The sensitivity of the rods and cones to light energy are a function of the wavelength of the light. Also, the difference between the sensitivity of the rods and cones is inversely related to the wavelength of the light. Consequently, sole reference to the sensitivity curves of the rods and cones as the prime argument for the use of red in preference to white or any other color is not well founded (54).

One area where many studies have been conducted, and where conclusions cannot easily be drawn, is that of visual acuity. (8, 12, 13, 29, 32, 40, 43). Throughout the literature pertaining to visual acuity, there is a contradiction of results. For the most part, these discrepancies are probably due to differences in experimentation. This would include different methodology, type of equipment, calibration procedures, and a combination of variables. Unfortunately, many researchers omit such details in writing their reports. These are four distinct measures or types of visual acuity. The values obtained in tests differ widely for the different types of acuity. Therefore, one should not apply visual acuity data to any situation until he is sure the data was obtained for the type of acuity required in that situation. From various studies, it can be concluded that the minimum luminances required for efficient pilot performance within the cockpit lie in the one log-step range 0.01 to 0.1 mL. If the critical visual angles (two to ten minutes of arc) are considered in relation to these display luminances, it is clear that these acuity adaptation levels lie on the curve of cone function. At those levels of luminance, between 0.01 and 1.0 mL, which are of especial interest in conection with night flight, there is an interaction effect between retinal illumination and spectral distribution such that the curves for monochromatic lighting cross the white-light curve. In this low range of cone vision, acuity under red light is as good, if not better, than acuity under white lighting (8, 32). A study was made of near visual acuity. Results indicated better near (14 inches) visual acuity under 0.1 ft.L of white light versus red for acuity demands of 20/30, 20/40, and 20/50. At 20/20, visual acuity was very poor under both red and white light. At 20/70, visual acuity was near 100 percent under both red and white light of 0.1 ft.L (25).

Heglin, in his report (29), points out several general statements concerning visual acuity and various parameters. Among these are:

1. Acuity is best under photopic light conditions and poorest under scotopic seeing conditions.

2. An increase of illumination increases visual acuity as well as speed of recognition.

3. As contrast is decreased, size must be increased, especially for lower contrast percentages, in order to maintain threshold acuity.

4. Luminance contrast, color contrast, illumination level, and exposure time are much more important factors in acuity than color of illuminant.

It should be noted, that even in these general statements, more than one type of visual acuity is considered.

In conclusion, the merits of red lighting versus white lighting have to be evaluated in terms of the mission requirements. If the mission requires a great deal of external vision, and thus maximum dark adaptation, then a red lighting system is better. However, if external vision is not a prime consideration, then a white lighting system should be considered.

Major Cockpit Lighting Problems

There are several areas where problems have been found which are independent of the color of the lighting system. The major problem is uneven lighting between instruments across the panel. This situation forces the pilot to make the choice to either turn all the lights up to compensate for poor illumination on a few instruments or leave the dim instruments at an unreadable low level. The first choice degrades dark adaptation and reduces out-of-cockpit visibility while the second choice slows his instrument cross-check and denies him critical information (42).

A second problem is the warning lights. Many pilots feel that even though they immediately attract attention, they are too bright at night. Also, if a malfunction cannot be corrected, the light remains on and becomes a source of irritation until the mission is over (9, 42).

Still another trouble spot, are the problems with reflections and glare. During night low level and weapons delivery work, reflections and glare on the canopy are particularly annoying to the pilot. Reflections from the cockpit lights can also affect instrument readability by causing glare on the glass of an instrument face (10, 27, 42, 56). The most troublesome reflections, according to the pilots, were those between the 9 and 10 o'clock position on the left side and those between the 2 and 3 o'clock position on the right side.

Auxiliary Lighting

A survey was conducted among Air Force pilots to get their opinions on cockpit lighting and related problems. Most of the pilots did not consider the auxiliary cockpit lighting adequate. One specific problem noted was the C-4 type of auxiliary map light. The pilots reported the C-4 was awkward to handle, poorly located, and difficult to remove or replace (42).

Most pilots also felt that the kneeboard lights were inadequate. The standard Air Force issue kneeboard contains a two C-cell battery powered light, equipped with a variable red or white filter. According to the pilots, the light fixture on the kneeboard is too close to the reading surface, has poor contacts, the batteries wear out quickly, and it is very unreliable. Many pilots reported the use of flashlights instead of kneeboard lights (33, 42).

Floodlights are another source of problems within the cockpit. Floodlights were reported as the most common source of glare (42). Very few of the reports addressed the problem of what color light should be used for a floodlighting system. Those that did, noted that floodlights will be turned up when there is a greater need for information within the cockpit, and therefore seemed to prefer a white floodlighting system (42).

Glare Reduction

Several methods are currently being investigated in an effort to reduce the adverse effects fo glare. An evaluation of a reflection reducing coating for instrument cover glass seemed to show merit. The coating reduces specular glare by increasing light transmission from the dial face and thus enhancing contrast between the light figures and the dark background of the dial (56).

A comparison was made between the standard canopy and a tinted reduced-glare canopy to determine the effect on detection from the ground and to determine if there was any reduction of internal reflection during the day or at night. There was no significant difference in detectability between the reduced-glare and the standard canopies. Also, there was no reduction of internal reflection with the reduced-glare canopy. There were, however, many new maintenance problems to contend with (62). For these reasons, the use of a reduced-glare canopy was not advised.

Luminance Levels and Legibility

Several points were made about luminance levels and legibility that were independent of the color of the lighting system employed. It should be noted, however, that legibility is better under red light than with white when both are set to levels giving equal luminance (27). Intano, in his study, showed quite clearly that legibility under red light was significantly better than white light at lower luminance levels and equal to white at the higher levels (32). The points that were brought out are:

1. Pilots may use the entire range of brightness levels possible with gradual dimming to maximize dark adaptation and out-of-cockpit visibility (32).

2. Small instruments become difficult to read at low levels of illumination (42, 55).

3. As far as digit legibility is concerned, the level of illumination is the most important factor (51).

4. There is an improvement in performance from 0.011 to 0.044 foot-Lamberts, but relatively little additional change for brightness levels higher than this (51).

5. Finely graduated dials become difficult to read at lower brightness levels because minor scale marks become difficult to see (55).

6. At higher levels, the fine dials are more accurate because no interpolation is required (55).

7. There appears to be a critical brightness level for performance which does not appear to change materially regardless of dial diameter or scale markings. This level is between 0.02 and 0.05 ft.L (55, 64).

Future Considerations

At present, there are two areas where proposals are being developed and evaluated for possible use in future cockpit display systems. Both of these areas would be greatly enhanced by the use of a white lighting system. The first is the use of mulitcolored displays. The advantage of white over red in this case is obvious. As was pointed out earlier, white lighting provides better color discrimination. Red lighting provides no color discrimination. The same is true for any monochromatic lighting system.

The second area where proposals are being considered is in the field of electroluminescent lighting. With this technique, the instrument dial surface will be an electroluminescent plate. When an electric voltage is applied, the dial will light up. All the markings will have a more uniform brightness than has been possible with any previous system. Although brightness will decay slowly with age, there will be no sudden failures comparable to lamps burning out as at present. The electroluminescent technique offers a variety of colors, for coding purposes, although the basic color will most likely be white. One of the most difficult colors to provide is red (28, 49).

Another theory which has been proposed for possible consideration, is that of a blue lighting system. The reasoning behind this theory is that there is a good chance that some other lighting system may better facilitate cone adaptation and be more suitable for situations in which only maximum cone sensitivity is required. The luminance function shows that a filter transmitting only the red end of the spectrum permits vision with the cones while allowing the rods to adapt. By looking at the other end of the curves, it can be seen that a filter transmitting only blue would, at low illumination levels, permit vision with the rods while allowing the cones to adapt. It should be noted here that rod vision is limited to objects subtending greater than five minutes of arc and requires non-foveal vision. It may be established through future research that the rods are sufficient for minimal acuity tasks such as the reading of specially redesigned dials in a cockpit illuminated with low-level blue light. If this happens, a blue lighting system may become desirable for the situation in which the operator needs to recognize and identify objects against the night sky intermittently while monitoring instruments within the cockpit (43, 64).

Ultraviolet lighting is not desirable for cockpit illumination, because the most stable phosphors now available are chiefly yellow or yellow-green, which are not desirable wave lengths for night lighting. If stability is achieved for a red phosphor, ultraviolet lighting could be used, provided that reflections are controlled and some red floodlighting is used to aid in general orientation. Another disadvantage of ultraviolet lighting is that it causes fluorescence of the eye lens, which reduces vision by causing haze (28, 64).

CONCLUSIONS

Before any conclusions can be drawn from the presented material, one must first know what type of helicopters will be in use when new lighting systems will be available. The next generation of helicopters are already on the drawing boards. But, before lighting systems can be designed for tomorrow's helicopters, it must be known under what conditions these helicopters will be expected to fly. By meeting the most critical conditions which will be encountered, all other situations will automatically be satisfied. The color of the lighting system does not matter for use in daytime flights; therefore, the system has to be developed for night flight. Tactical situations will also dictate that these be low-level night flights. The new generation of helicopters will probably contain several cathode ray tubes (CRT). The CRT's will be capable of providing target, flight, and navigational information. It is safe to assume that the aircraft will be flown

over terrain with no visible ground lights, other than reflections, so the electronic sensors will have to provide the pilot with all the external information he needs to fly the aircraft.

The assumption that all new helicopters will be equipped with CRT's might not be valid. However, those aircraft without CRT's may be restricted to daytime hours or flight at higher altitudes. For those aircraft flying at the higher altitudes, their external visual cues will be limited to those for navigation and attitude as their primary tasks will probably be enroute navigation. Since aircraft flying at higher altitudes do not contribute to the determination of critical situations, they will not be considered any further; but the fact that aircraft of this type do exist is acknowledged.

Therefore, for all practical purposes, the pilot during a low level night mission, is flying instrument meteorlogical conditions (IMC). If the electronic sensor displays provide all external information needed for mission accomplishment, then is there a need to maintain dark adaptation and provide maximum external vision? Therefore, the ability to obtain internal information is the prime consideration. All evidence would indicate the use, in this situation, of a white lighting system with a white floodlighting system. White lighting would also enhance possible future display systems. However, these electronic sensors are not currently in use. If their development does ot meet the expectations, and external vision is still required for a safe mission, then the continued use of red lighting is indicated.

Future research is still needed in many areas. These include:

1. An improvement of the lighting balance between instrument across the panel.

2. An improvement of the light diffusion across instruments.

3. An improvement of auxiliary lighting.

4. Reduction of reflections and glare.

5. Improved marking schemes for legibility under red or white light.

6. Quantification of visual requirements for low level or NOE night operations.

It has been the aim of this literature review to point out these problem areas and give future researchers the source of trouble in cockpit lighting system. By finding solutions to the problems which have been identified, and those which did not show up in this review, it is hoped an optimum cockpit lighting system can be found.

ANNOTATED BIBLIOGRAPHY

1. Advisory Group for Aerospace Research and Development. Aircraft instrument and cockpit lighting by red or white light. AGARD CP-26, October 1967.

2. Advisory Group for Aerospace Research and Development. Problems of vision in low level flight. AGARD 107, 1967.

3. Advisory Group for Aerospace Research and Development. Problems of the cockpit environment. AGARD CP-55, March 1970.

The various technical activities of AGARD in the field of science and technology related to aerospace are carried out by permanent panels and committees composed of leading scientists and their contemporaries from each NATO nation.

The material presented in this publication is the extended summaries of papers delivered at the Avionics Panel's XVIth Technical Symposium covering "Problems of the Cockpit Environment." Emphasis has been placed on the "Crew in the Cockpit" viewpoint with contributions and representatives of the Aerospace Medical Panel, Flight Mechanics Panel and Guidance and Control Panel providing their specialists' views.

4. Attneave, F. Some informational aspects of visual perception. AFPTRC TR-54-33, August 1954.

5. Aviation Daily. White lighting best for cockpit, AF maintains. Page 339, December 29, 1966.

6. Baker, H. D. Some direct comparisons between light and dark adaptation. Office of Naval Research/FSU, June 1955.

7. Barnes, J. A. The effect of cockpit lighting systems on multicolored displays. Technical Memorandum 30-70. U. S. Army Human Engineering Laboratory, Aberdeen Proving Ground, MD, 1970.

This report analyzes the performance of 42 subjects reading aircraft instruments comprising various combinations of pointer/background colors viewed with both Army/Navy IPL red and Air Force blue-white cockpit lighting systems. The results rank the pointer/background color combinations according to the least number of scale-reading errors they produced.

8. Bauer, R. W. Night flight vision I: Research problems and methods. Technical Memorandum 12-68, U. S. Army Human Engineering Laboratory, Aberdeen Proving Ground, MD, 1968.

Review of the literature in aviation and in vision, and consideration of photometric methods availab :, raise a number of fundamental questions about cockpit lighting. Dark adaptation and acuity must be examined in relation to the total cockpit light flux, the ambient illumination outside the cockpit, and the spectral composition of the light flux. Furthermore, the aircraft mission requirements must be incorporated into design decisions. The program of research recommended has a character consistent with that proposed by Bartelt, Twist and Lazo (1966). Photopic and scotopic luminance, photometric and radiometric methods, color coding and contrast, and acuity at low luminances are reviewed. Analytic methods are described, and areas requiring fundamental human factors research are indicated.

9. Bauer, R. W. Night flight vision II: Psychophysical comparisons of three colors of cockpit lighting. Technical Memorandum 13-68, U. S. Army Human Engineering Laboratory, Aberdeen Proving Ground, MD, 1968.

Three different spectral distributions of cockpit display lighting were investigated as to their effects on dark adaptation and visual acuity during night flight. These distributions were instrument and panel lighting red, tungsten (clear) white, and Air Force (lunar) blue-white. Cockpit-lighting brightness (photopic luminance), color and color combinations with the addition of indicator lights were controlled, and effects on dark adaptation and distant visual acuity outside the cockpit were measured. Interactions among lighting colors, photopic and scotopic visual acuities, and luminance thresholds for objects of different sizes were shown. Results were discussed in relation to the literature on dark adaptation and night vision in flight.

10. Bauer, R. W. & Florip, D. J. Night vision with a binocular system. Technical Note 3-69, U. S. Army Human Engineering Laboratory, Aberdeen Proving Ground, MD, 1969.

Recovery of dark adapted acuity after the use of a night vision system was observed in two experiments within a flight simulation facility. The users of these two systems gave up about one log cycle in dark adaptation (luminance required) to gain about one log cycle in viewing objects 5 to 10 minutes or larger. One hundred percent recovery of rod dark adaptation required from 3.0 to 4.2 minutes. Because of their target brightness sensitivity, color characteristics and acuity ranges, these systems can be appropriately compared with human unaided dark adapted rod vision.

11. Boivin, R. H., Schmidt, J., & Balfe, P. J. Pave low-evaluation of a terrain following radar system for the HH-53 helicopter. AFFTC TR-73-11, Air Force Flight Training Center, Wright Patterson AFB, OH, March 1973.

This report presents the results of a flight test and evaluation program of a prototype terrain following/terrain avoidance (TF/TA) AN/APQ-141 radar system for search and rescue applications installed on an HH-53B helicopter. The report also presents an evaluation of the addition of symbology to the low light level television (LLLTV) display installed as part of the limited night recovery system (LNRS) in the same aircraft.

12. Brown, J. L. Luminance thresholds for the resolution of visual detail during dark adaptation. WADC TR-52-12, Wright-Patterson Air Development Center, Wright-Patterson AFB, OH, January 1952.

Luminance thresholds for the visual resolution of various widths of alternating light and dark lines were determined at various times during dark adaptation. The finest gratings, representing high degrees of visual acuity, show only a single cone curve that drops from a high luminance threshold during the first moments of dark adaptation to a final steady level that is reached after about 7 to 10 minutes in the dark. Coarse gratings produce a duplex curve that shows an initial cone portion and a delayed rod portion. Visual acuity is a parameter that sets the position of a given curve on the log threshold axis. The higher the degree of resolution required, the higher the dark adaptation threshold. At a constant grating luminance, visual acuity rises rapidly to a maximum during dark adaptation; the higher the luminance, the earlier and more rapid the rise and the higher the maximum. Visual acuity increases at all dark adaptation times with increase in luminance. Implications of these findings for instrument lighting are discussed.

13. Brown, K. T. & Grether, W. F. The effects of pure red and low-color temperature white instrument lighting upon dark adapted visual thresholds. AF TR-6470, April 1972.

The effects of pure red and low color temperature white flood lighting upon completely dark adapted visual thresholds have been determined. The red light was adjusted to brightness levels which pilots have been found to use as the minimal, normal, and maximal levels for night flying. For each brightness level of the red light, a brightness was found for the low color temperature white light at which aircraft instruments were equally legible under the two lighting systems. Both a simulated instrument panel and a pure white panel were used as viewing panels. Six subjects were tested under each lighting condition.

A higher brightness proved necessary with the low color temperature white light than with the pure red light in order to attain equal legibility of instruments. Both lighting systems at all brightness levels caused small increases in visual thresholds above the completely dark adapted state. When the simulated instrument panel was illuminated at the normal brightness level, thresholds after viewing low color temperature white light were 0.15 micro-microlamberts above thresholds after viewing pure red light. This value defines the approximate sacrifice in dark adaptation which would be made if white lights, operated at low voltage, were substituted for red lights in flood lighting aircraft instruments. The white lighting would also be more visible to dark adapted enemy observers. However, the white lighting system would make colors in the cockpit appear more natural, which would facilitate such tasks as map reading. When operated at normal voltage, the white lighting system could also provide high intensity illumination for special purposes such as thunderstorm flying, very high altitude daytime flight, and simulated instrument flying with the amber hood and blue goggles.

14. Burnett, G. L., & Cunningham, L. M. Operational study of pilots visual requirements. NADC-AC-6803, Naval Air Development Center, February 1968.

This report is a preliminary study in which visual tasks, lighting utility, and ambient external light levels were examined on a time-task basis in an instrumented F4B aircraft. Methods included photometric and electrical recordings of the internal and external lighting environment of the aircraft. Also pilot interviews, questionnaires, and direct observations of pilots in the F4B and other aircraft were employed. The results indicate that the methods employed are practical and that the visual tasks performed and ambient external lighting conditions are important determinants of lighting utility inside the cockpit.

15. Chalmers, E. L. The effect of illumination on dial reading. AF TR-6021, August 1950.

Eight subjects participated in this experiment to obtain some new data on the effect of lowered illumination on the speed and accuracy of dial reading. Dials of 12 types and two sizes were used.

Interpolation and other local errors are found, for hard-to-read dials, to increase progressively as brightness decreases. Gross errors and reading times, on the other hand, change very little with decreasing brightness until a critical level is reached. This critical level is very similar for all dials with a given size of marking.

Other data which are described indicate that the critical level for any given dial can be determined from number reading tests or by obtaining judgments of minimum acceptable illumination levels from careful observers.

16. Chapanis, A. An evaluation of problems of chart reading under red illumination. NRC/VC Jan 53-C, January 1953.

The present report was prepared by Dr. Alphonse Chapanis, of the Johns Hopkins University, to summarize the status of problems encountered in chart reading under red illumination.

Material for the report was obtained primarily from a conference held on 30 September 1952, at the Naval Medical Reserach Laboratory, U. S. Submarine Base, New London, Connecticut.

The present report summarizes the concensus of the New London conference and includes such additional notes, discussion, and references as were supplied by various persons following the circulation of the first draft of the report of the conference.

17. Chapanis, A., & Halsey, R. M. Luminance of equally bright colors. ONR/JHU R-166-1-88, Office of Naval Research, Washington, DC, January 1955.

An analysis has been made of the Y values, of luminances, or 342 colored filters which had been previously matched in brightness by direct visual comparison. The CIE diagram was partitioned into 20 zones and the average luminance calculated for the colors in each zone. The results show regular shifts in the average luminance values over the CIE diagram. Supplementary experiments support the principal findings. In general, the data agree with other recent studies which show that, for colors of equal brightness, saturated colors require less luminance than desaturated ones. However, there is a reversal of this trend in the yellow area since the point of maximum luminance for a given brightness occurs there. The latter finding agrees closely with recent predictions by MacAdam based on his model of visually homogeneous color space.

18. Chisum, G. T. Color discrimination and chart reading under red and low-intensity white light. AGARD CP-26, October 1967.

The type and level of cockpit illumination are important considerations in providing a work space in which flight personnel can operate efficiently. In order to reach a satisfactory decision on these considerations, it is essential to show the kinds, and relations among, visual tasks required of personnel inside and outside the cockpit, and the conditions external to the cockpit which will effect performance of visual tasks.

Operational analyses of the tasks required of flight personnel have not been made. The lack of these analyses has led to decisions on lighting based on theoretical considerations and frequently conflicting experimental results. One of the most obvious tasks required of flight personnel is to read topographical charts. With only a few exceptions, features of maps and charts are distinguished by colour discriminations. Data are presented on the accuracy of colour discrimination required in reading topographical charts and the identification of map features under red and low intensity white light.

The accuracy of colour discrimination is significantly greater under white light as compared with red light. The results on the identification of chart features are more equivocal. Factors in addition to colour discrimination apparently influence the accuracy of map reading.

19. Cole, E. I. Brightness levels of three instrument lighting systems used by pilots flying at night. AF TR-6031, August 1950.

Information obtained from twelve pilots flying a C-47 aircraft at night using three different instrument lighting systems is presented. These systems were: (1) red flood, (2) indirect red, and (3) ultra-violet. Brightness levels used by the pilots were recorded for the three systems under varying flying conditions. These conditions were (1) normal night flying, (2) night instrument (maximum), and (3) minimum brightness necessary for safe flight. For normal conditions, the lowest brightness level used occurred under red flood and highest under indirect red. At minimum levels, indirect red was lowest followed by ultra-violet and red flood. At maximum levels (night instrument condition), red flood was highest, indirect red next, and ultra-violet the lowest although this position of ultra-violet represented the maximum available brightness range for this system. Pilot opinion showed varying preferences for the different conditions. Indirect red was preferred as being the most pleasant and comfortable system and red flood was preferred as being the most effective of the three.

20. Condon, G. W., Rundgren, I. W., & Connor, W. J. Army preliminary evaluation II, YO-3A Airplane. USAASTA-69-14, August 1970.

A second Army preliminary evaluation (APE II) of the YO-3A airplane was conducted from 2 through 6 February 1970. Nine test flights encompassing 6 flight hours were conducted from Crows Landing Naval Auxiliary Landing Field, California. Several simulated mission profiles were flown during day and night visual-flight-rule operations to determine if certain deficiencies and shortcomings found during APE I had been adequately corrected by the contractor. Additionally, personnel from the U. S. Army Electronics Command and Night Vision Laboratory conducted an evaluation of the airplane mission equipment.

21. Cosby, M. A. Service suitability phase of the navy evaluation of the HH-3A Helicopter. NATC ST-4R-71, February 1971.

The HH-3A Helicopter was evaluated to determine its service suitability in performing the limited all-weather combat search and rescue (SAR) mission. Within the scope of the evaluation, the HH-3A Helicopter cannot perform the limited all-weather combat SAR Mission. Four deficiencies which preclude mission accomplishment with a satisfactory degree of safety and effectiveness must be corrected prior to aircraft delivery to operational squadrons. The ability to easily read and interpret the flight and navigation instruments of the HH-3A Helicopter enhances its ability to perform the all-weather combat SAR mission and this characteristic should be incorporated in future designs.

22. Crook, M. N. Aeronautical charts under red light. WADC TR-54-198, Wright-Patterson Air Development Center, Wright-Patterson AFB, OH, May 1954.

The general problem of designing charts for legibility under red cockpit light is examined in the context of related problems. The characteristics of charts and the techniques for presenting information on them are analyzed and evaluated in relation to possible methods for improving red light legibility. Several lines of research carried out under this project are reviewed, and two experimental charts are exhibited and described. Methods for improving red light legibility, within the framework of present size and space limitations and production techniques, are summarized.

23. DeBruine, C. J., & Milligan, J. R. In-flight test results on mission-oriented cockpit lighting requirements. AFFDL TR-71-142, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, OH, September 1971.

The report describes an experimental program designed to obtain baseline cockpit illumination data using three types of electroluminescent display lighting. A series of three in-flight experiments was flown in a T-39 aircraft by highly experienced USAF pilots. The mission profiles were designed to simulate different types of operational flights by progressively increasing the external visual task loading on the pilot. Both objective measurements and pilot opinion data were obtained on display illumination under external ambient illumination ranging from twilight to night no-moon conditions.

24. Dohrn, R. H. Luminance measurements for red and white-lighted aircraft instruments. AGARD CP-26, October 1967.

A Spectra Brightness Spot Meter, Model U. B. 1/2, was used to measure the luminance level of flight instruments during night flight. Measurements were taken in red and white-lighted cockpits of United States Air Force high-performance and cargo aircraft. Recordings were made of pilot adjustments for maximum, minimum, and optimum instrument luminance levels used during night flight. The maximum instrument luminance levels ranged between .05 and 0.3 ft.L (foot lamberts). Most of the normal luminance levels ranged between .01 and .03 ft.L. There was less variation of instrument luminance between different aircraft than between instruments within the same type of aircraft. The minimum luminance level deemed necessary for safe flight ranged from .001 to .01 ft.L. The distribution of light over single instruments or groups of instruments shows extreme gradations for the cockpits studied. Since a single unnecessarily bright instrument light may have the same detrimental effect as an entire instrument panel on the pilot's level of dark adaptation, it is important that the luminance of individual instruments be balanced and evenly distributed. It was concluded that there is a definite need to evaluate and upgrade the quality of instrument lighting.

25. Dohrn, R. H. Near visual acuity under low-level red and white light. SAM TR-68-119, October 1968.

The near visual acuity of 17 subjects between the ages of 35 and 45 years was measured under white light and red light of a 0.1 ft.L luminance level. The near visual acuity was significantly better under white light for the acuity demands of 20/30, 20/40, and 20/50. The visual acuity was equally good under red or white light when the acuity demand was 20/70 or larger, and the visual acuity was equally poor under red or white light when the acuity demand was 20/20.

26. Goldfarb, S. R. White lighting of aircraft instruments and consoles. WCLC-59-14, May 1959.

To provide information on the suitability of white lighting for aircraft instruments and consoles where applicable. This report is based on engineering and flight test evaluations.

27. Grether, W. F, & Reynolds, H. N. The effect of red versus white lighting on dark adaptation using a simulated instrument panel for preadaptation. AGARD CP-26, October 1967.

Evidence for the superiority of red aircraft instrument lighting is based largely on dark adaptation experiments with uniform preadaptation fields and relatively high luminance values. Results of such experiments have questionable validity for the low luminance levels and

patterned fields characteristic of instrument panels. This paper reports experiments in which a simulated instrument panel was used for preadaptation, and luminance values corresponded to those used by pilots in aircraft. A comparison was made of red, white, and blue-filtered white instrument lighting, at several luminance levels. Dark adaptation thresholds were measured as quickly as possible after subjects scanned the panel. The results show a relatively small superiority of red over white instrument lighting in terms of preserving dark adaptation. An additional finding was that, when adjusted for equal luminance, the red lighting gives somewhat better instrument legibility.

28. Grether, W. F. Trends and new developments in aircraft instrument lighting. AMRL TR-69-144, December 1969.

Following a brief historical review of aircraft instrument lighting, the advantages and disadvantages of red lights are discussed.

29. Heglin, H. J. Navships display illumination design guide section II: Human factors. NELC/TD 223, July 1973.

The intent of this section is to provide human factors guidelines for use in design of visual displays--supported by research data, tables, graphs, and charts for general reference and followed by application specification materials that offer standards and tolerance limits. It is not possible in a work such as this to entirely support the various existing (and constantly changing) applicable military and industry standards and specifications. Where contracts demand departures from the guidelines given, this section's principal utility may be as a basis for evaluating related design or performance tradeoffs.

30. Huchingson, R. D. Cockpit lighting/pilot night vision study. Report 2-56620/2R-3027, Vought Aeronautics, March 1973.

This report presents the results of a joint research effort by the U. S. Navy Lighting Group at the National Bureau of Standards and the Human Factors Group at Vought Aeronautics. The data was collected in 1969 following the A-7E Cockpit Lighting Mockup.

31. Hulbert, E. O. Report on dark adaptation time to become dark adapted after stimulation by various brightnesses and colors. NRL H-2035, March 1943.

The times for an average observer to become dark adapted after being exposed to various stimulations were measured for:

(a) Stimulations by white and red light of intensity from 0.1 to 120 foot candles.

(b) Stimulations by light in the spectral range from 366 to 650 u of intensities 1 and 6 foot candles.

32. Intano, G. P. Legibility of various sized letters under aviation red, "lunar" white, and neutrally-filtered incandescent white lighting systems. AGARD CP-26, October 1967.

Three types of cockpit lighting were employed to illuminate a simulated instrument panel: aviation red, "lunar" white, and neutrally-filtered incandescent white. The different lighting systems were equated at seven brightness levels: 0.005, 0.01, 0.05, 0 10, 0.15, 0.19 ft.L, and rated voltage. The legibility of photographically reduced Armed Forces Visual Acuity Charts

was measured. Results showed increases of performance above brightness levels reported in past research. Legibility was significantly better under aviation red than either of the two "white" systems. No significant differences were found between the "lunar" white or neutrally-filtered incandescent white lighting. Further research should continue on various types of legibility within cockpit environments using test material closely approximating that found in operational aircraft. Wide ranges of brightness levels should be used. Operational studies of aircraft cockpit light levels should be integrated with the laboratory studies.

33. Kennedy, R. S., & Berghage, T. E. Pilot attitudes on dark adaptation and related subjects. Special Report 65-4, June 1965.

The night accident rate for carrier landings is five times the day rate. This raises the possibility that visual errors caused by lack of dark adaptation may be involved.

Completed questionnaires regarding the importance of being adapted to darkness prior to and during night time aircraft carrier operations were received from 71 experienced naval aviators. Analysis of their responses showed that, generally, their opinion of the usefulness of dark adaptation is an individual matter; if the aviator had ever experienced its need, he was likely to be concerned.

The greatest value to an aviator of being adapted to the dark was said to be during launch. After being airborne, however, the aviator's major visual problem lies in reflection of the instrument lights which reduces visibility and can affect dark adaptation. Poor knee-board lighting and difference in instrument light intensity were mentioned as other irritating problems.

34. Ketchel, J. M, & Jenney, L. L. Electronic and optically generated aircraft displays. JANAIR - 680505, Office of Naval Research, Washington, DC, May 1968.

This report presents work which was performed under the Joint Army Navy Aircraft Instrumentation Research (JANAIR) Program, a research and exploratory development program directed by the United States Navy, Office of Naval Research. Special guidance is provided to the program for the Army Electronics Command, the Naval Air Systems Command, and the Office of Naval Research through an organization known as the JANAIR Working Group. The Joint Army Navy Aircraft Instrumentation Research Program objective is to conduct applied research using analytical and experimental investigations for identifying, defining, and validating advanced concepts which may be applied to future, improved Naval and Army aircraft instrumentation systems. This includes sensing elements, data processors, displays, controls, and man/machine interfaces for fixed and rotary wing aircraft for all flight regimes.

35. Kislin, B. & Dohrn, R. H. The effect of night cockpit luminance, red and white, on central and peripheral visual performance. AGARD CP-26, October 1967.

Eighteen subjects were light adapted for 20 minutes to an approximated cockpit luminance of 0.1 foot Lamberts (ft.L) red light and 0.1 ft.L incandescent white light. Thresholds for peripheral perception and central identification were taken with a Goldmann Weekers adaptometer. A transilluminated Landolt C subtending a 32.5′ arc overall, and a 6.5′ arc opening served as the target for peripheral detection and central identification.

Statistically, there appears to be some advantage in peripheral retinal sensitivity after extended exposure to 0.1 ft.L level red light over white of equal intensity. The foveal recognition threshold appears to be the same after either exposure. From a nighttime, operational viewpoint for jet aircraft, there should be no requirement for the retention of full scotopic capability to the

detriment of color perception. The maintenance of maximum rod sensitivity in observation aircraft and helicopter pilots engaged in night operations is questioned. Until further resolution of the visual capability from hover, and low and slow aircraft under starlit conditions in mission achievment, they should continue using red lit instrumentation.

36. Kurschner, D. Visual functions as determining factors for quality and amount of effective panel and cockpit lighting. AGARD CP-26, October 1967.

Swift changes in engineering and in operational flight environments necessitate a reassessment of the problems of effective panel and cockpit lighting within increasingly shorter periods of time. The interaction between changed environmental factors and optical-physiological factors must of course also be considered. From a series of general physiological requirements as to quality and amount of panel cockpit lighting, visual acuity, accommodation, adaptation, colour sense and visual field are taken as the determining factors in this respect and conclusions drawn accordingly. Considering in addition the environmental factors (spectral distribution of light at different altitudes), wavelengths from the red part of the spectrum up to approximately 500 m or rather, if possible, orange-yellow up to greenish-yellow at the outside, should be given preference for panel and cockpit lighting . The intensity of illumination must not, however, exceed 0.02 lux. As operational flight environments may shift the compromise between the requirements for highest possible visual acuity and maximum adaptation in favour of the latter, a flexible illumination system in this wave band is desirable.

37. Lazo, J. Human engineering investigations of the interior lighting of naval aircraft. NAMC ACEL-347 Part 14, August 1957.

An experiment was performed in order to investigate: (1) the usefulness of a central master indicator used in conjunction with a peripherally located cautionary indicator panel, (2) the relative effectiveness of positive (opaque digits and illuminated background) and negative (opaque background and illuminated digits) cautionary legend displays and, (3) the optimum digit size for positive and negative cautionary legend displays.

38. Lazo, J. Human factor aspects in aircraft interior lighting. AGARD CP-26, October 1967.

In the development of modern aircraft weapon systems, there is an increased emphasis on the utilization of design criteria based on the capabilities and limitations of the aviator. With respect to current aircraft interior lighting, the basic visual variables relating to the display design and lighting of aircraft informational presentation systems will be discussed in detail. The development of current red and white lighting system designs, based on the application of data derived from the continued study of these variables, will be presented.

The need for specific information on the aviator's visual requirements, both within and external to the aircrew station, in modern aircraft will be discussed. A systematic investigation which includes a complete operational analysis of the aviator's visual tasks to permit the establishment of valid lighting design criteria compatible with the aviator's needs on a mission requirement-time structure will be proposed.

39. Liang, H. Aircraft night flight and instrument flight. FTD HT-23-995-68, July 1969.

The author surveys the general knowledge of night flying and instrument flying which includes: the six categories of meters on the meter panel, the physical and psychological aspects of aviators, training, internal and external lighting system of aeroplanes, airport lightings, and signals of airport control towers.

40. Luria, S. M. Accommodation and scotopic visual acuity. NSB/MRL R-352, April 1961.

Changes in scotopic acuity as a function of varying states of natural accommodation have been measured with targets at various distances and luminances. Results for two observers showed that the amounts of negative accommodation needed to produce maximum acuity increased with decreasing luminance or increasing target distance at a constant luminance. The amount of natural negative accommodation needed for maximum acuity was much less than has been found with the use of spectacles and natural accommodation for infinity. There appeared to be a critical luminance level at which changes in accommodation produced minimal changes in acuity. The effect of red versus white fixation lights was also investigated.

41. Mercier, A. The effect of red versus white instrument lighting on the dark adaptation index. FPRC 255, May 1966.

A study has been carried out to determine whether there are any marked differences in the level of dark adaptation when a pilot views an instrument panel illuminated by red light, or by low-temperature white light giving, however, equal legibility.

The level of night vision which it is possible to achieve when scanning an instrument panel, depends upon the time for which the instrument panel is observed, the amount of scanning, and the number of markings, as well as the level of illumination of these markings.

In order to relate thresholds of visual sensitivity to practical aspects, these thresholds are expressed in terms of the time required for the eye to reach that particular level of sensitivity. This is referred to as the dark adaptation index.

By means of a field study, making use of the preferred levels of instrument illumination employed by pilots flying actual sorties, it is intended to measure, by the same technique, the amount of night vision required for carrying out various operational roles.

42. Milligan, J. R. A survey of United States Air Force pilot opinion on cockpit lighting. AFFDL TR-70-13, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, May 1970.

A survey was conducted among Air Force pilots to determine the techniques used for adjusting cockpit illumination problems. Rating scales, personal interviews, and a questionnaire were employed to collect data. The results showed that a wide variety of problems, many of which were mission oriented, exist in cockpit illumination systems, problems enumerated were unsatisfactory auxiliary cockpit lights, high instrument light levels caused by uneven lighting within instruments and across the entire instrument panel, reflections on the canopy, and difficulty in reaching light dimming controls. On the basis of the survey results, a systems approach is recommended for the solution of these problems.

43. Mitchell, R. T., & Mitchell, R. R. Visual acuity under blue illumination. MIT/Lincoln 58G-0018, Massachusetts Institute of Technology/Lincoln Laboratory, Cambridge, MA, February 1961.

Visual acuity was compared under white and blue illuminations of equal intensities. At a viewing distance of 13 inches no difference in performance was found. In two experiments at 10 and 26 feet, the angular size of the minimum detail which could be resolved was 40-50 percent greater with blue light than with white. When observers wore -1.0 diopter lenses at the far distance in the blue condition their acuity was statistically indistinguishable from acuity under white light.

The decrease in acuity is ascribed to the axial chromatic aberration of the eye. A blue illuminant typical of selective spectrum lighting systems used with dim cathode ray tubes results in an induced myopia of .60 diopters corresponding to a far point of 65 inches. Methods of compensating this effect are briefly discussed.

44. Mueller, C. G. Some factors in human visual discrimination. HRM 200/1 Appendix 193, June 1951.

45. Muick, C. J. Operational evaluation of filtered and unfiltered white aircraft instrument lighting. AGARD CP-26, October 1967.

This study was initiated at the request of the Society of Automotive Engineers A20A Committee on flight crew station lighting, because there were those instrument manufacturers who felt that the Air Force specification for white integrally lighted aircraft instruments was too difficult to meet. Arrangements were made with the USAF Instrument Pilot Instructor School, Randolph AFB, Texas, to provide the test vehicle, a T-38 trainer, and the subjects. The manufacturers supplied the modified (unfiltered) white instruments, and the Air Force supplied filtered white instruments ranging in age from six months to four years, with the exception of two new instruments.

Nineteen subject pilots flew both the filtered and unfiltered panels during scheduled night missions. The preference was significantly in favor of the Air Force filtered white lighting system.

46. Personnel Research Section, Adjutant General's Office. Studies in visual acuity. PRS Report 742, Department of the Army, Washington, DC, 1948.

The purpose of the studies reported herein, was to examine various aspects of visual acuity through a factor analysis of correlations among tests of visual acuity, to select the most representative tests, and to investigate item difficulty and scoring methods. The studies were conducted by the Personnel Research Section, AGO, Department of the Army.

47. Peterson, C. J., & Smith, H. A. Development of high contrast electroluminescent techniques for aircraft displays. AFFDL TR-66-6, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, OH, April 1966.

This paper outlines the steps taken by the Air Force Flight Dynamics Laboratory to develop a new display technology capable of meeting display requirements of future manned weapon systems. A description is made in the first part of this paper identifying the basic concept and resulting development of high-contrast electroluminescent (EL) displays both from an engineering and psychophysical standpoint. The problem of display legibility, quite often confused with display brightness, is also discussed with respect to its effect on the limitations of EL displays. Finally, information is presented identifying how this limitation was overcome and why such progress is considered to be an important contribution to the development of solid-state displays. The second part of this paper describes the human factors aspects of the high-contrast EL program. The inherent weakness of transilluminated displays, the variables related to readability, the effects of the anticipated upper limits of environmental lighting, and the study of one of the first high-contrast EL displays are discussed.

48. Projector, T. H., & Hardesty, G. K. C. The computation and use of cone-to-rod specifications NSRADC EL-25-69, September 1969.

The note summarizes the principles that underlie the concept of a cone-to-rod ratio (CRR) and supports the use of CRR in evaluating the suitability of light for situations where it is necessary to consider the dark adaptation of personnel. It is pointed out that many existing specifications continue to refer to CRR's that are derived from computations based on a now obsolete table of scotopic visual efficiency. The logical use of the commission international de L'eclairage(International Commission on Illumination) 1951 standard instead of the old data produces CRR's that are quite different numerically but in many instances can be converted from one basis to the other. Figures are given to illustrate the differences. Computational forms are supplied for the entry of spectroradiometric data from sources or of spectral transmittance data from filters to be used with various blackbody light sources as well as several standard nonblackbody sources.

49. Reynolds, H. N. The visual effects of exposure to electroluminescent instrument lighting. Human Factors, 1971, 13 (1).

This report describes two experiments with electroluminescent aircraft instrument lighting. In the first experiment, white electroluminescent, green electroluminescent, and red incandescent lighting were compared for their effects on dark-adapted, scotopic absolute and acuity thresholds, using a simulated T-38 instrument panel for light exposure. In the second experiment, white, green, and yellow electroluminescent and red incandescent light were compared in terms of legibility of a transilluminated letter-acuity chart. Exposure to red incandescent lighting at 0.05 ft.L produced the lowest absolute and acuity thresholds, with white and green electroluminescent producing higher thresholds in that order. Although threshold differences between lighting colors were statistically significant, the absolute differences in visual sensitivity were small for practical purposes. Luminances required for equal legibility of transilluminated letters of various sizes were about the same for red incandescent and white, green, and yellow electroluminescent lamps. Electroluminescent lighting of aircraft instruments is discussed.

50. Rock, M. L. Visual Performance as a function of low photopic brightness levels. AF TR-6013, November 1950.

This study had as its purpose, a systematic investigation of performance on several representative visual perceptual tasks as a function of brightness at low photopic levels. Four types of tasks were studied: judgement of magnitude of a common illusion (Muller-Lyer); absolute threshold for horizontal motion of black and white stripes; accuracy of binocular depth perception; and performance on a series of simple addition tasks. Ten subjects, rigorously screened for excellence of vision, served in each of these experiments. Each task was performed at five brightness levels: 0.005 (0.008 for the addition task), 0.01, 0.05, 0.1, and 1.0 foot Lamberts.

The results showed for all four experiments a critical brightness level, below which decreases in brightness were associated with increasingly poor performance, and above which increases in brightness produced little or no improvement in performance. The critical level for motion threshold was in the 0.1 foot Lambert region. It is suggested that on visual tasks in which maximal performance is desired with a minimum brightness, (e.g., to conserve dark adaptation) the illumination should be adjusted to yield brightness values of approximately 0.05 to 0.1 foot Lamberts.

51. Schapiro, H. B. Factors affecting legibility of digits. WADC TR-52-127, Wright-Patterson Air Development Center, Wright-Patterson AFB, OH, June 1952.

This study was concerned with the manner in which the legibility of single digits (as measured by speed of reading) is affected by the interactions of the following variables: level of illumination, style of digit, and ratio of stroke-width to overall height of digit. Illumination levels used were: 0.011, 0.044, 0.145, and 0.975 foot Lamberts. Digit styles were: AHD 10400, Berger, Craik, and Mackworth. Stroke width-height ratios were: 1:5, 1:6.25, 1:8, and 1:10.

Twelve subjects with good vision, each read 3200 digits in a factorially designed experiment. Analysis of the results showed that: (1) in the determination of legibility, level of illumination was the most important factor studied in this experiment; there was a marked improvement in performance from 0.011 to 0.044 foot Lamberts, but relatively little additional change for brightness levels higher than this; (2) the Mackworth digits were the most legible with the AHD 10400 digits a very close second; (3) ratios of 1:5, and 1:6.25 were superior to others tested; and (4) except for illumination level, differences between subjects were more important than any other source of variability in the experiment.

52. Semple, C. A., Heapy, R. J., Conway, E. J., & Burnette, R. T. Analysis of human factors data for electronic flight display systems. AFFDL TR-70-174, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, OH, April 1971.

The report presents the results of a review of 1178 technical documents dealing with human factors considerations in electronic flight display systems. Design-oriented human factors data are presented for the following families of design considerations: display size, information coding, alphanumerics, scale legibility, visual acuity, display system resolution, flicker, contrast ratio requirements, and environmental variables including ambient illumination, vibration and acceleration. Quantitative, design-oriented functional relationships are emphasized. Research recommendations are made where existing data were found inadequate for design use. A model is presented for organizing the variables impacting upon human performance as a function of electronic flight display system design.

53. Sleight, R. B. The effect of instrument dial shape on legibility. ONR-R-166-1-33, Office of Naval Research, Washington, DC, April 1948.

In spite of a wide diversity of instrument dial types in use today, objective evidence is lacking which designates one type of dial as more desirable than another from the standpoint of legibility. In this study, comparisons were made of five dials of different shapes, all in common use for certain purposes. It was the aim of the study to determine the relative legibility of these several differently shaped dials.

54. Smith, H. A., & Goddard, C. Effects of cockpit lighting color on dark adaptation. AFFDL-TR-67-56, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, OH, May 1967.

The report is addressed to the general problem area of the effects of color of illumination on early dark adaptation. An analysis of the relevant published literature is presented as it relates to the relative benefits of red cockpit lighting as opposed to white or other colors for night flying. A report of a demonstration which compared the effects of green and white lighting to red lighting on subsequent early dark adaptation is included. An annotated bibliography of the literature reviewed for the report is also presented. A systems approach to cockpit illumination is stressed.

55. Spragg, S. D. S. Dial reading performance as related to illumination variables III: Results with small dials. AF TR-6040, November 1950.

This experiment is a repetition, with different stimulus materials, of an experiment on the speed and accuracy of reading high contrast photographic reproductions of instrument dials. The earlier study had used 2.8 inch diameter dials with a coarse (100 x 10) scale. The present experiment used a 1.4 inch dial with a relatively fine scale (100 x 1).

Ten subjects, rigorously screened visually, each read 50 dials at each of the following brightness levels: 0.005, 0.01, 0.05, 0.1, and 1.0 foot Lamberts. The results, which are in essential agreement with those of the first experiment, show that: (1) from 0.005 up to 0.05 foot Lamberts dial reading performance improves rapidly (as measured by error frequency and time) as brightness increases; and (2) from 0.05 up to the highest brightness level used, 1.0 foot Lamberts, increments of performance are slight and relatively unimportant.

The present results corroborate and give added generality to the previous finding that for dial reading performance there is a critical brightness level in the region of 0.02 to 0.05 foot Lamberts, below which performance suffers marked decrement as brightness is decreased and above which increases in brightness produce but slight increments in performance.

56. Stowell, H. R., & Bauer, R. W. Photometric evaluation of reflection-reducing coating for aircraft instrument cover glass. Technical Memorandum 12-69, U. S. Army Human Engineering Laboratory, Aberdeen Proving Ground, MD, August 1969.

Comparisons were made between plain instrument cover glass used on aircraft Instrument panels and cover glass deposited with multilayer antireflection coating conforming to MIL-C-14806 and AMS 2521. Photometric measurements of reflections, light transmission and contrast indicated the effectiveness of the reflection-reducing coating.

Reflected glare from the face of instruments was significantly reduced by the reflection-reducing coating and increased light transmission enhanced contrast on instrument dial faces.

57. Stowell, H. R., Florip, D. J., & Bauer, R. W. FP-50 flight display effects on vision. Technical Note 2-70, U. S. Army Human Engineering Laboratory, Aberdeen Proving Ground, MD, March 1970.

The Kaiser FP-50 Flight Display Unit is designed to provide a visual display of aircraft attitude and certain tactical information to the pilot. A cathode ray tube (CRT) is used to display the information. It was anticipated the FP-50 display lighting in the cockpit would affect the pilot's outside visual performance during night flight.

This report summarizes both photometric measures and human factors experiments on the FP-50 with pilot subjects. Results indicated that the white light of the display had negligible effects on dark adaptation and visual acuity when operated at suitable low-level brightness for night flight. It was discovered, however, filters enhanced contrast of the display by three or four times at these low luminances.

58. Uhlaner, J. E. A study of the relation between photopic and scotopic visual acuity. PRS Report 858, June 1950.

Early in World War II it was realized that the U. S. Army had a problem in evaluation of the ability of soldiers to see at night. The need for training in night-seeing techniques carried with it the problem of proper personnel selection devices, which in turn led to the development of the Army night vision tester. However, the relationship between day visual acuity and night visual acuity had not been determined. If a high degree of relationship between the two abilities exists, there is no need to measure them separately; on the other hand, if there is little or no relationship, separate measures of the two are needed. The present study sought to determine the relationship between day (photopic) visual acuity and night (scotopic) visual acuity by testing 200 soldiers with a battery of day vision tests and a night vision test. These men were studied under standardized and carefully controlled conditions. The results of this study showed that there was a positive relationship between the measures of day and night visual acuity for this group. This relationship was not high enough to substitute a man's score on one ability for his score on the other. This finding suggests that if personnel selection procedures must provide certain instruments appropriate to measuring both types of vision, for the present at least, one measure of each type would be necessary. However, there is an indication that further study may determine levels of day vision which will give reasonable assurance of above-average night vision ability for a wide-range population.

59. Uhlaner, J. E. A pilot study of the relationship between scotopic visual acuity and acuity at photopic and mesopic brightness levels. PRS Report 963, July 1952.

A long range study has been underway to develop more effective methods of assessing night vision ability of military personnel. The present study, as part of the long range study, attempted to obtain an indication of the relationship between scotopic (starlight) visual acuity and mesopic (partial moonlight) and photopic (daylight) visual acuity. Specifically, the Army was interested in developing a test of night visual performance to be administered at a mesopic brightness level because such a test would be practical and economical.

Scotopic acuity scores were moderately related to photopic acuity scores. Substantially higher relationships were obtained between scotopic and mesopic acuity scores. These correlations were obtained even though the scotopic tests were administered to the subjects a full year before the other tests.

The correlations obtained in this pilot study indicated the feasibility of developing a mesopic test sufficiently useful in measuring night visual ability. Such a test would have the following advantages: shorter adaptation time and hence more rapid testing, less cumbersome and less expensive equipment, less dependence on light-tight conditions, and fewer testing personnel. In the practical military situation, these factors might well be critical in determining whether or not a test of night vision could be adopted for operational use.

60. University of Rochester. Dial reading performance as related to illumination variables: I: Intensity. MR-MCREXD 694-21, October 1968.

The purpose of the experiment presented in this report was to investigate the relation between level of illumination and dial reading performance under night viewing conditions. Such data are important for specifying the minimum level of illumination at which satisfactory instrument reading can be carried out by the aircraft pilot under night flying conditions.

61. University of Rochester. Dial reading performance as related to illumination variables II: Spectral distribution. MR-MCREXD 694-21A, December 1948.

A report is presented which has been prepared by Dr. S. D. S. Spragg and Mr. Milton L. Rock of the University of Rochester under the title of "Dial Reading Performance as Related to Illumination Variables: II, Spectral Distribution." The purpose of the reported study was an investigation of the relation between dial reading performance and color or spectral distribution of the illumination under which the dials are viewed.

62. U. S. Army Combat Developments Experimentation Command. Reduced-glare canopy experiment - Supplement 2 to attack helicopter-clear night defense (CDEC 43.7) Phase I. ACN 18894, February 1973.

This is a report on exploratory training performed in support of USACDEC conducted at Hunter Liggett Military Reservation, California from 5 July to 15 December 1972. Its purpose was to establish the state-of-the-art capability to conduct clear night antitank missions by defining a performance baseline for standard unaided helicopters from which techniques of employment could be further developed. The concept was to address the objectives by training aviators and ground players to perform the tactical missions anticipated to be requirements for the primary experiment. For the purpose of this training, it was assumed that these tasks would be similar to those generated by Experiment 43.6, Attack Helicopter - Daylight Defense, in a night environment, and that scenario was used as a training vehicle. There was the degree of familiarity with the terrain by aviators that is expected of an operational unit that is well oriented on major land forms but does not have an intimate knowledge of nap-of-the-earth conditions.

63. Wilcox, R., and Cole, E. L. The effects of two instrument lighting systems on dark adaptation. WADC TR-52-263, December 1952.

Four pilots with normal vision were tested for the effects of the standard indirect red and red-flood aircraft lighting systems on dark adaptation. Data were gathered in a completely blacked-out cockpit while the aircraft was in a hangar and also during conditions of normal night flight. Significant differences in dark adaptation thresholds were found between the hangar and flight phases and between the low and high levels of light intensity used. It is concluded that the flight conditions of starlit night sky affect dark adaptation levels to a significant degree.

64. Wulfeck, J. W., Weisz, A., & Raben. M. W. Vision in military aviation. WADC TR-58-399, November 1958.

The requirements of vision in military aviation are analyzed in the light of the human observer. Practical problems of perception encountered in many phases of flying are analyzed and discussed. A comprehensive bibliography is included in each section of the report for those who are interested in a more detailed approach to a particular subject.